EMERGENCY EVACUATION OF SUBWAY STATIONS DURING A DISASTER, STUDY CASE: "STATION 5 OF TURO"

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ABSTRACT

Here we observed emergency evacuation of Station 5 of Tabriz Urban Railroad Organization (TURO) by using Distinct Element Method (DEM). In DEM, analysis can compute the position of each person step by step by solving the equation of motion. 5 cases with different number of people in platform and concourse level are considered and evacuation simulation is done simultaneously for both levels. Density of people near exits and gates is observed by considering control zones in platform and concourse levels. Evacuation time and maximum density on exits are calculated quantitatively for considered cases and the obtained results are discussed. According to simulation results, we can conclude that number of people has great influence in evacuation time and maximum density of people so it is essential that before construction of public buildings such as subway stations, evacuation simulations considering maximum expected number of people in order to meet safety requirements should be done.

INTRODUCTION

Safety of people is a primary consideration in any building. There are many risk factors which can cause casualties such as earthquake, fire, flood, terrorism, etc. A building should service in both normal condition and emergency situations. When large numbers of people are or gather together in a place such as subway stations, beside structural damage issues, people evacuation during a disaster is of great importance. One way to predict the evacuation behavior of people is evacuation simulation.

Distinct Element Method (DEM) is an approach to be applied in evacuation simulation purposes. There are limited simulation models using DEM to simulate evacuation behavior and crowd dynamics.

Kiyono et al. (1996), considered circular DEM elements as human beings and investigated behavior of the crowd flow that evacuated from an enclosed space to outside through the passage or the steps. They found that the model they proposed was able to simulate evacuation during a disaster. Kiyono et al. (1998) used DEM to simulate evacuation behavior during a disaster. They used circular elements and proposed an algorithm in which elements can avoid collision and pass each other naturally. They determined DEM parameters such as spring constants and driving force for human body based on experiments and simulated evacuation behavior for the explosion accident occurred at the underground shopping center near Shizuoka Station in 1980. Kiyono et al. (2000) used the same method to simulate the evacuation of an underground mall in Kyoto. Kiyono and Mori (2004) used elliptic elements to simulate emergency evacuation behavior during a disaster and validated the technique by comparing the simulation results with a real pedestrian flow.

Langston et al. (2006) developed a DEM technique for modeling crowd dynamics. They presented each element by three overlapping circles. The model was tested on a single enclosure entry scenario where some model parameters were scaled then it was used on a multi enclosure entry scenario. The potential for further application was demonstrated on hypothetical scenarios on the London Underground. Langston et al. (2009), compared the predicted model behavior with actual video footage shot at various locations around University Park Campus, Nottingham. They found that it did not match well to the video footage when people were moving toward each other, as in case of contra-flow on a walkway. In order to improve the model, they introduced an avoidance algorithm to the model to make it more realistic in those cases. Alighadr et al. (2011) observed effect of exits' width and number of people on emergency evacuation time and density on exits for Seghatol Islam Mosque of Tabriz Bazaar. Mahdavian et al. (2012) used DEM to simulate tsunami evacuation behavior during the 2011 East Japan Great Earthquake. Alighadr et al. (2012) did simulation of emergency evacuation of Timche Muzaffariyye of Tabriz Historical Bazaar Complex in order to evaluate evacuation time and maximum density on exits. Alighadr et al. (2013) simulated evacuation behavior for classes building of ASMU. They concluded that location and distance of exits are important factors on evacuation time and density on exits and it is better that exits have enough distance from each other to reduce congestion on exits. Here we observed emergency evacuation of Station 5 of Tabriz Urban Railroad Organization (TURO) by using DEM. DEM is a numerical method which can calculate each element's position by solving equation of motion step by step.

STUDY CASE INTRODUCTION

Study case takes place in Station 5 of Tabriz Urban Railroad Organization (TURO). Plans considered for simulation and exits of platform and concourse levels are shown in figures 1 and 2, respectively. Density of people near exits and gates is observed by considering control zones in platform and concourse levels. 5 different cases regarding number of people at platform and concourse levels are considered which is depicted in table 1.

Table 1. Number of people at platform and concourse levels

Case No.	1	2	3	4	5
People number at platform level	100	200	300	400	400
People number at concourse level	100	100	100	100	200

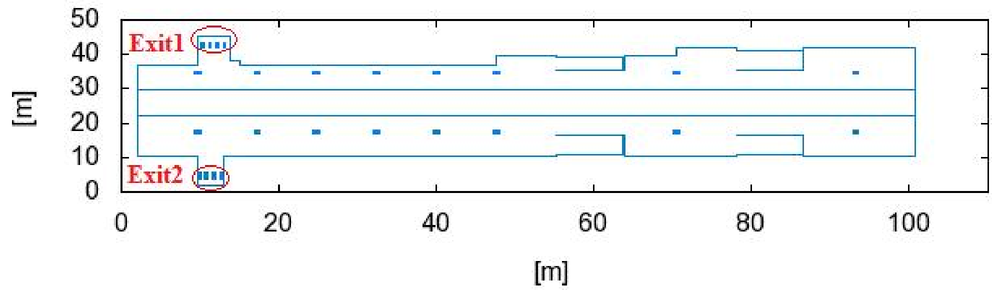

Figure 1. Platform plan and exits

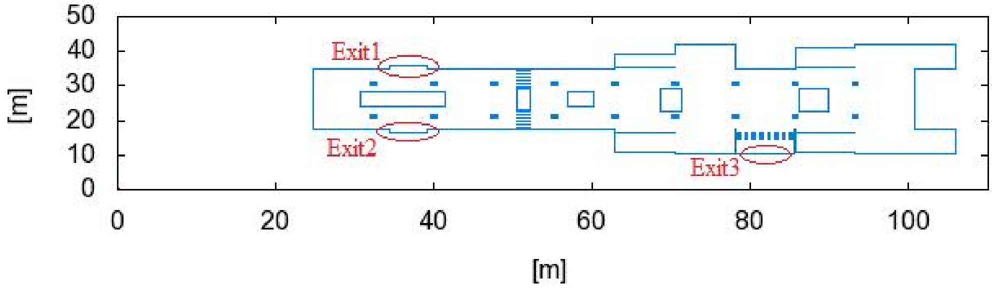

Figure 2. Concourse plan and exits

Evacuation simulation is done for platform and concourse levels simultaneously by using DEM for all cases.

DEM SIMULAION METHOD

Distinct Element Method was used to simulate the emergency evacuation from a confined area. Human body is modeled as a circular element. Contact force acts on human body through virtual spring and virtual dashpot.

In DEM, analysis can compute the position of each element (person) step by step by solving the equation of motion. The program simulates movement and decision making by means of adding the psychological forces to the physical forces. Algorithm that can consider avoidance, overtaking, and pass between elements naturally, is used.

The governing equations of motions are:

$$m_i \ddot{x}_i(t) = f_i^{\,x}(t) \quad (1)$$

$$m_i \ddot{y}_i(t) = f_i^{\,y}(t) \quad (2)$$

in which m_i is mass of i-th element, and $f^{\,x}$ and $f^{\,y}$ are various forces including driving force acting on the element in x and y directions, respectively.

Assuming that the acceleration is constant between small time interval, Δt, the following equations can be obtained.

$$\dot{x}_i(t) = \dot{x}_i(t-1) + \ddot{x}_i(t-1)\Delta t \quad (3)$$

$$\dot{y}_i(t) = \dot{y}_i(t-1) + \ddot{y}_i(t-1)\Delta t \quad (4)$$

$$x_i(t) = x_i(t-1) + \dot{x}_i(t-1)\Delta t + \frac{1}{2}\ddot{x}_i(t-1)\Delta t^2 \quad (5)$$

$$y_i(t) = y_i(t-1) + \dot{y}_i(t-1)\Delta t + \frac{1}{2}\ddot{y}_i(t-1)\Delta t^2 \quad (6)$$

The position of each element can be calculated sequentially by solving above equations step by step. Psychologically people tend to keep a constant distance from others when they walk or run.

In this study, this psychological distance is introduced as virtual radius. Independence of element spring, the virtual spring is also introduced. The contact judgment of two elements is determined by calculating the distance between the centers of two elements (Kiyono et al., 1998).

The parameters used for human body are based on experiments done by Professor Kiyono at Kyoto University. These parameters are illustrated in Table 2.

Table 2. Human body parameters (Kiyono et al, 2000)

Parameter	Value
Element spring constant (Normal)	1.07 x10^4 (N/m)
Element spring constant (Tangential)	5.35 x10^2 (N/m)
Element damping coefficient (Normal)	1.245 x10^3 (Nsec/m)
Element damping coefficient (Tangential)	2.79 x10^2 (Nsec/m)
Virtual spring constant (Normal)	6.62 x10^1 (N/m)
Virtual spring constant (Tangential)	3.31 x10^0 (N/m)
Virtual damping coefficient (Normal)	9.79 x10^1 (Nsec/m)
Virtual damping coefficient (Tangential)	2.19 x10^1 (Nsec/m)
Element radius	0.259 (m)
Virtual radius	0.72 (m)
Mass	3.62 x10^1 (kg)
Time interval	0.01 (sec)
Acceleration of driving force	0.837 (m/s2)

DEM EVACUATION SIMULATION RESULTS

We did simulations for considered 5 cases. Snap shots of evacuation behavior of case 5 for platform and concourse levels are shown in Figures 3 and 4, respectively. Exit3 is the main exit of concourse level and also people of platform level entering concourse level are evacuated through this exit and as it is seen in figure 4 congestion takes place there and there is no congestion on Exits 1 and 2.

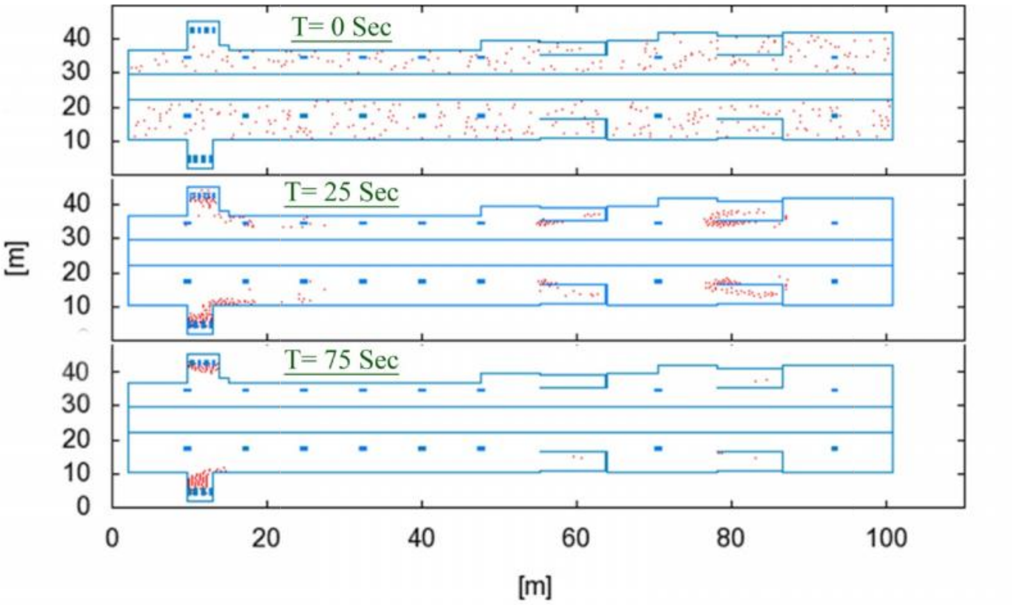

Figure 3. Snap shots of evacuation of platform level for Case 5

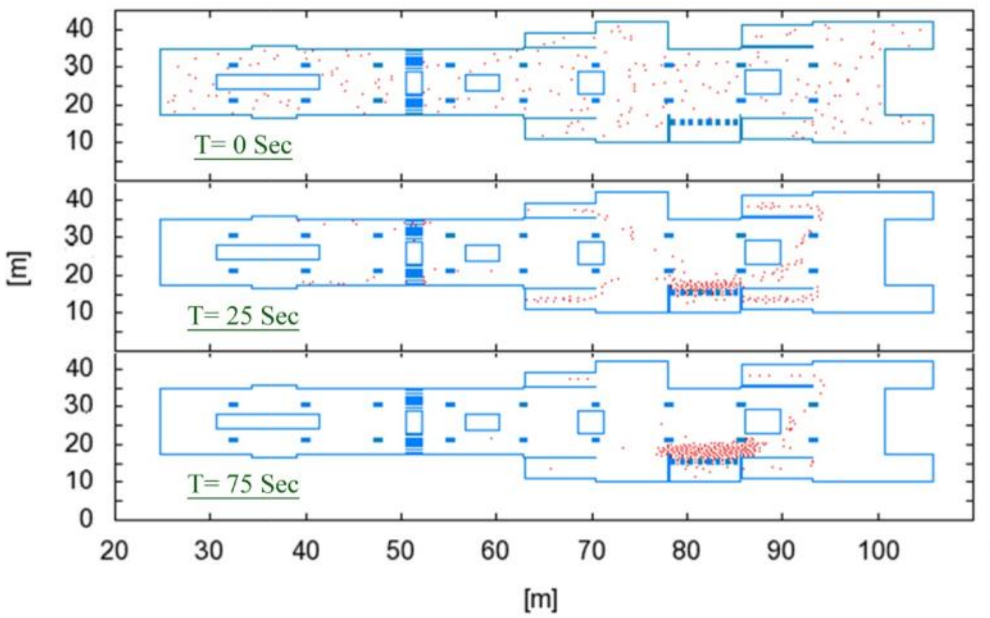

Figure 4. Snap shots of evacuation of concourse level for Case 5

Evacuation time for platform level is calculated to be 75, 140, 324, 438 and 438sec and for concourse level 110, 190, 370, 477 and 477 sec for cases 1 to 5, respectively which is depicted in figure 5. As results show by increasing the number of people from 100 (Case1) to 400 (Cases 4 and 5), evacuation time becomes 5.8 times for platform level. In concourse level not only the number of people in the level itself but also the number of people of platform level evacuated through the concourse level is effective in evacuation time. For example comparing Case1 to Case5, evacuation time becomes 4.3 times.

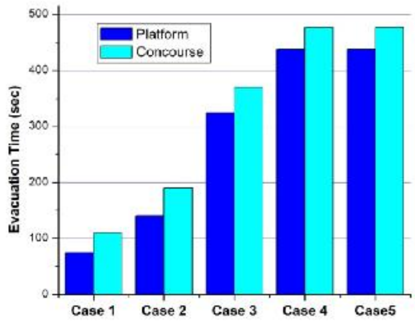

Figure 5. Evacuation time

Maximum densities on platform and concourse levels' exits are listed in Table 3. As an example time history of density on Exit 3 of concourse level up to 250 sec is depicted in figure 6.

Table 3. Maximum densities of considered control zones (person/m^2)

Case No.	1	2	3	4	5
Platform level	1.64	1.94	4.18	4.32	4.32
Concourse level	1.41	2.83	4.05	4.39	5.33

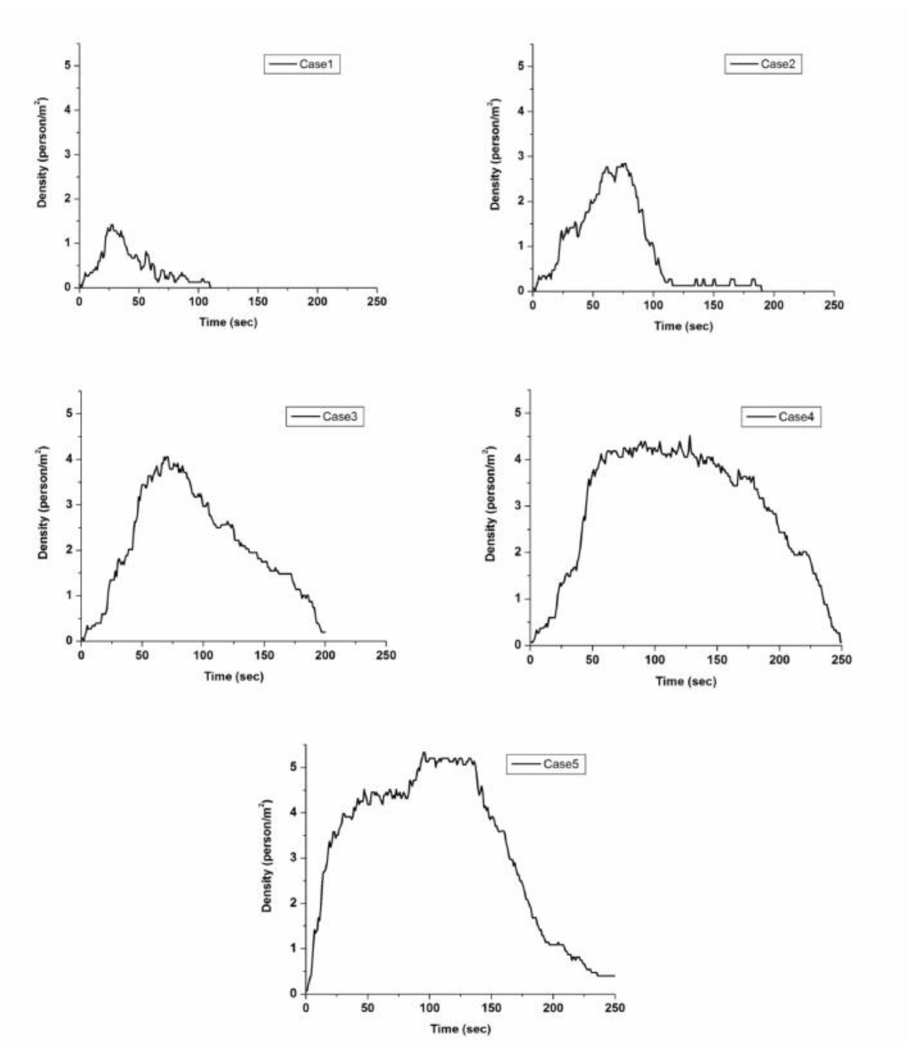

Figure 6. Time history of density on Exit 3 of concourse level up to 250 sec

As results show by increasing the number of people from 100 (Case1) to 400 (Cases 4 and 5), maximum density becomes 2.6 times for platform level and for concourse level comparing Case1 to Case5, maximum density increases by nearly 278 percent (of course number of people at platform level is an effective factor on density of concourse level).

Considering results of simulations discussed above, we can conclude that number of people has great influence in evacuation time and maximum density of people.

CONCLUSIONS

Safety of people is a primary consideration in any building. When large numbers of people are or gather together in a place such as subway stations, beside structural damage issues, people evacuation during a disaster is of great importance. Here we observed emergency evacuation of Station 5 of Tabriz Urban Railroad Organization (TURO) by using Distinct Element Method (DEM). 5 cases with different number of people in platform and concourse level are considered and evacuation simulation is done simultaneously for both levels. Evacuation time and maximum density on exits are calculated quantitatively for considered cases.

As results show by increasing the number of people from 100 (Case1) to 400 (Cases 4 and 5), evacuation time becomes 5.8 times for platform level. In concourse level not only the number of people in the level itself but also the number of people of platform level evacuated through the concourse level is effective in evacuation time. For example comparing Case1 to Case5, evacuation time becomes 4.3 times

Also results show by increasing the number of people from 100 (Case1) to 400 (Cases 4 and 5), maximum density becomes 2.6 times for platform level and for concourse level comparing Case1 to Case5, maximum density increases by nearly 278 percent.

Considering results of simulations discussed above, we can conclude that number of people has great influence in evacuation time and maximum density of people so it is essential that before construction of public buildings such as subway stations, evacuation simulations considering maximum expected number of people in order to meet safety requirements should be done.

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